This invention thus provides a silicon inverse opal with photonic properties in the range of visible light which may form high-luminosity silicon nanofoam-based LEDs. The nanoporosity is responsible for the emission of light, and the periodic macroporosity of the photonic crystal structure controls the propagation of the emitted photons. Compared to conventional porous silicon, the inventive material has much larger active surface area since the whole volume of the material is used in the process for creating nanoporosity. The nanoporosity is created on the device after the periodic macroporosity has been created. Thus, the photoluminescence in these silicon nanofoams is enhanced by about ten-fold over conventional porous silicon. In addition, by tuning the position of the photonic band gap of the photonic crystal structure, even further photoluminescence enhancement at particular wavelength bands of the photoluminescence spectrum may be achieved due to nonlinear effects at the photonic band gap edges. The invention provides very low density nanofoams, which are highly periodic (photon confinement in photonic bandgap) and have nanoscale porosity. The invention combines the advantages of porous silicon and silicon-based photonic crystals and can be used to produce light emitting photonic crystals that exhibit two-levels of porosity: periodic microporosity in the silicon inverse opal backbone and random nanoporosity obtained by making the silicon backbone nanoporous.

The examiner is correct that Zakhidov, et al. teaches a three dimensionally periodic microporous structural matrix of interconnecting, crystallographically oriented, monodispersed members having voids between adjacent members. However, as the examiner agrees, Zakhidov, et al does not show nanopores superimposed on their periodic micropores. This invention improves over Zakhidov, et al because the inventive material shows enhanced and spectrally controlled, tunable photoluminescence and electroluminesce. Photoluminescence in porous silicon is explained with quantum confinement of charges and excitations in the nanostructures created by the electrochemical etching of bulk silicon. Periodic photonic crystals confine and localize photons. According to this invention, a new material, a silicon nanofoam, couples the advantages of the porous silicon and photonic crystals. Such photonic crystals are

actively emitting photonic materials, with the nanoporosity being responsible for the emission of light, and the periodicity of the photonic bandgap structure controlling the propagation of the emitted photons.

Zakhidov, et al. shows the underlying dimensionally periodic microporous structural matrix of interconnecting, crystallographically oriented, monodispersed members, but *they do not show superimposed surface nanoporosity.*

Gole, et al shows a microporous structure with superimposed surface nanoporosity, but *no periodic microporous structure.*

However, it is submitted that there is no suggestion from the art that one should combine Zakhidov, et al. and Gole, et al to superimpose surface nanoporosity on a periodic microporous structure.

Zakhidov, et al certainly show a two or three dimensionally periodic microporous structural matrix of interconnecting, crystallographically oriented, monodispersed members having voids between adjacent members. However, that is where the similarity ends. Nowhere is Zakhidov, et al do they even mention a microporous structural matrix additionally having random nanoporous surface porosity. Nowhere in Zakhidov, et al, do teach or suggest nanopores superimposed on micropores.

First, the Zakhidov, et al materials are not necessarily light emitting or light transmitting. For example, diamond is not clearly a light emitting or light transmittal photonic crystal. Even if it were, this condition this is insufficient to meet the requirements of this invention. While one may intentionally transform their topographical structure, according to the techniques of the present invention, and make them into a light emitting or light transmitting photonic crystal, they are not inherently light emitting or light transmitting photonic crystals, nor are they taught to be such by following the teachings of Zakhidov, et al.

Applicants' claims describe a light emitting or light transmitting photonic crystal having a randomly nanoporous surface porosity. U.S. patent 6,261,469 to Zakhidov et al. at column 4, lines 52-57 teaches only a carbon foam having an average pore diameter of about 4Å to about 10Å, which carbon foam is <u>not</u> a light emitting or light transmitting photonic crystal. The previously submitted declaration from Dr. Ray H. Baughman, a co-inventor of the present application *and a co-inventor of the applied reference to Zakhidov, et al.* declares that the carbon foam described at column 4, lines 52-57 of Zakhidov, et al. is not a light emitting or light transmitting photonic crystal which comprises a two dimensionally periodic or three dimensionally periodic microporous structural matrix of interconnecting, crystallographically oriented, monodispersed members having voids between adjacent members, and said members additionally having randomly nanoporous surface porosity.

In short, while Zakhidov, et al. shows a two dimensionally periodic or three dimensionally periodic microporous structural matrix of interconnecting, crystallographically oriented, monodispersed members having voids between adjacent members, the structure is not necessarily light transmitting, and does not show or suggest superimposed nanoporosity. Gole, et al shows a microporous structure with superimposed surface nanoporosity, but *no periodic microporous structure.* It is submitted that there is no suggestion from the art that one <u>should</u> combine Zakhidov, et al. and Gole, et al to superimpose surface nanoporosity on a <u>periodic</u> microporous structure. There is no suggestion from Zakhidov, et al. and Gole, et al, to produce nanoporosity after the <u>periodic</u> macroporosity has been created. There is no suggestion from Zakhidov, et al. and Gole, et al that photoluminescence in a <u>periodic</u> microporous structure would be enhanced by about ten-fold over a conventional porous structure. There is no suggestion from Zakhidov, et al. and Gole, et al that by tuning the position of the photonic band gap of a photonic crystal structure, even further photoluminescence enhancement at particular wavelength bands of the photoluminescence spectrum may be achieved due to nonlinear effects at the photonic band gap edges. As described in Applicants' specification, nanoporosity is responsible for the emission of light and the

periodic microporosity of the photonic crystal structure controls the propagation of the emitted photons. In no respect does Zakhidov et al. teach or suggest a light emitting or light transmitting structure having a randomly nanoporous surface porosity on the micropores as defined by Applicants. Indeed, Zakhidov et al. goes no further than discussing steps for the removal of their material A from an A-B composite structure. Accordingly, the structure as described by Applicants is structurally different than any structure described by Zakhidov et al. For these reasons it is submitted that the rejection over Zakhidov, et al in view of Gole, et al should be withdrawn.

Claims 13 and 14 stand rejected under 35 U.S.C. 103(a) over Zakhidov et al. in view of Gole, et al and further in view of Russell et al. (U.S. patent 6,093,941). It is respectfully submitted that the rejection is not well taken. The arguments with regard to Zakhidov et al. and Gole, et al apply equally herein and are repeated from above. The Examiner has applied Russell et al. to show that a photonic band gap material can be deposited on a sapphire substrate. It is respectfully asserted that the combination with Russell et al. fails to overcome the differences between Zakhidov et al. in view of Gole, et al, and the claimed invention. More specifically, the combination of Zakhidov et al. in view of Gole, et al and Russell et al. still fails to teach or suggest a <u>periodic</u> microporous structure having superimposed randomly nanoporous surface porosity which is also capable of emitting and/or transmitting light. For these reasons, it is submitted that the rejection has been overcome and should be withdrawn.

Claim 17 stands rejected under 35 U.S.C. 103(a) over Zakhidov et al. in view of Gole, et al and further in view of Koops (U.S. patent 6,064,506). It is respectfully submitted that the rejection is not well taken. The arguments with regard to Zakhidov et al. in view of Gole, et al apply equally herein and are repeated from above. Koops teaches an optical multipath switch with electrically switchable photonic crystals. The Examiner has applied Koops to show that it would be obvious to have a liquid crystal material imbibed on the photonic crystal of the invention. However, similar to Russell et al., the combination with Koops fails to overcome the differences between Zakhidov et al. in

view of Gole, et al and the claimed invention. More specifically, the combination of Zakhidov et al. in view of Gole, et al and Koops still fails to teach or suggest a periodic microporous structure having superimposed randomly nanoporous surface porosity which is also capable of emitting and/or transmitting light. For these reasons, it is submitted that the rejection should be withdrawn.

Claims 45, 46, 48 and 49 stand rejected under 35 U.S.C. 103(a) over Zakhidov et al. in view of Gole, et al and further in view of Jewell (U.S. patent 5,617,445). It is respectfully submitted that the rejection is not well taken. The arguments with regard to Zakhidov et al. in view of Gole, et al apply equally herein and are repeated from above. Jewell teaches a quantum cavity light emitting element having cavities and a light emitting material within the cavities. The Examiner has applied Jewell to show that it would be obvious to deposit a metal layer on opposite surfaces of a photonic crystal. The Examiner has also applied Jewell to show that it would be obvious to have a light emitter positioned to direct light onto the photonic crystal of the invention, and also to show that it would be obvious for such a light emitter to transmit light having the claimed wavelength range. However, similar to Russell et al. and Koops, it is respectfully asserted that the combination of Zakhidov et al. in view of Gole, et al with Jewell fails to overcome the differences between Zakhidov et al. in view of Gole, et al and the claimed invention. More specifically, the combination of Zakhidov et al. in view of Gole, et al and Jewell still fails to teach or suggest a periodic microporous structure having superimposed randomly nanoporous surface porosity which is also capable of emitting and/or transmitting light. For these reasons, it is submitted that the rejection should be withdrawn.

Claim 47 stands rejected under 35 U.S.C. 103(a) over Zakhidov et al. in view of Gole, et al , further in view of Jewell and further in view of Koyama et al. (U.S. patent 6,462,356). It is respectfully submitted that the rejection has been overcome. The arguments with regard to Zakhidov et al. in view of Gole, et al and Jewell apply equally herein and are repeated from above. Koyama et al. teaches a light emitting device having a light

emitting section and a waveguide section on a substrate, which waveguide section transmits light from the light emitting device section. The Examiner has applied Koyama et al. to show that it would be obvious to have an electrode attached to the electrically conductive, optically transparent layers of the claimed invention. However, similar to Russell et al. and Koops, it is respectfully asserted that the combination of Zakhidov et al. in view of Gole, et al with Jewell and Koyama et al. fails to overcome the differences between Zakhidov et al. in view of Gole, et al and the claimed invention. More specifically, the combination of Zakhidov et al., in view of Gole, et al Jewell and Koyama et al. still fails to teach or suggest a periodic microporous structure having randomly superimposed nanoporous surface porosity which is also capable of emitting and/or transmitting light. For these reasons, it is submitted that the rejection has been overcome and should be withdrawn.

The undersigned respectfully requests re-examination of this application and believes it is now in condition for allowance. Such action is requested. If the examiner believes there is any matter which prevents allowance of the present application, it is requested that the undersigned be contacted to arrange for an interview which may expedite prosecution.

Respectfully submitted,

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I hereby certify that this paper is being facsimile transmitted to the Patent and Trademark Office (FAX No. 703-872-9306) on September 10, 2004

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